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FIRST PROGRESS REPORT
ON
PROTECTIVE COATINGS

BY

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Exterior and Interior Coverings Section
Building Technology Division

Report to the
Materials Division
Structures Research Department
U. S. Naval Civil Engineering Research & Development Laboratory
Construction Battalion Center
Port Hueneme, California

NBS

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To

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1. INTRODUCTION

In March 1952, the Department of the Navy discussed with representatives of the National Bureau of Standards two problems encountered in desert area operations. They are as follows: (1) the protection of glass and metal surfaces from the abrasive action of wind-blown sand and (2) the protection of tools and other metal objects to permit comfortable handling when they are subjected to intense heating upon exposure to direct sunlight.

An initial proposal for an attack on the problem was submitted in April 1952, in which the possibility of using organic plastic coatings in the attainment of both objectives was suggested. In the proposal, a copy of which is attached as Appendix 1, the work was divided into two stated objectives as follows: (1) the suitability of abrasive-resistant organic coatings for glass and metal surfaces would be determined and recommendations for coating materials prepared, and (2) non-conductive and reflective coatings for metal would be evaluated and recommendations prepared.

The possibility of attaining the second objective by a blind selection of coatings without the benefit of theoretical considerations was recognized as being too small to warrant a test program. As a consequence, the experimental procedures discussed below were designed with the primary objective of combating abrasion, but with the provision that the solar heating problem be kept in mind during the preparation of the test specimens.

2. HISTORY

2.1 Previous Investigations

To the best of our knowledge, the sponsor has carried out no investigation concerning the first problem. However, a preliminary study was made at Fort Hueneme on protective coatings for tools and metal objects to permit handling when subjected to intense cold.

A contact was also made with the Bureau of Ordnance, Department of the Navy, regarding abrasive resistance but no information was available.

2.2 Reported in Literature

See Section 4.3.

3. EXPERIMENTAL

3.1 Methods of Application

Transparent coatings of two types were used in the preliminary stages of the project: (1) those submitted in sheet or film form, and (2) those submitted in solution or dispersion form. The types submitted in sheet form were mounted on a glass base by one or both of the following methods: (1) by wetting the glass with a solvent and pressing the film on the wetted area at a pressure of approximately 2000 psi, and (2) by wetting both glass and film with a transparent adhesive and pressing them together at the pressure used above.

The coatings submitted in solution form were applied by brushing. In the work to date, film thickness was not measured, but it will be determined gravimetrically in future work. A Payne-Fisher dip coater has been obtained to facilitate the preparation of uniform films.

3.2 Abrasion

The abrasion apparatus used in the initial work consisted of a sand reservoir constructed from an oil can, mounted inversely over a 1/8-inch brass tube, fitted with a tee at the point of entry of the sand and connected to a high-pressure air line by a rubber tube. Pressures varying from 4 to 15 psi were used in the experimental stages. The abradant originally employed was 24-30 mesh Ottawa quartz sand. It was fed by gravity through an orifice

into the air stream at a rate of 16 grams per minute. The air-sand mixture impinged upon the specimen which was mounted vertically at distances varying for 1/4 inch to 10 inches from the nozzle.

During the initial trials, it was found that with the large particle size of the 24-30 mesh sand, the desired matte pattern was not obtained. As a temporary expedient, 100-200 mesh silicon carbide was selected which, from visual observation, gave the desired pattern. It was decided that in future tests, a fine-grained sand, approximately of this particle size range, will be used as a standard.

3.3 Measurement of Haze

For measuring the extent of haze due to abrasion on the samples, the integrating sphere method for photometric measurements has been adopted. The abrasion is evaluated in terms of light scattered, i.e., the amount of diffusion of the parallel light incident on the sample caused by the abraded surface. The results will be expressed as % Haze, which may be defined as follows:

$$\text{Haze } \% = \frac{Ts}{Td} \times 100 \quad \text{when} \quad \begin{array}{l} Ts = \text{amount of light scattered.} \\ Td = \text{amount of light transmitted.} \end{array}$$

3.4 Weathering

No preliminary work has been accomplished on this phase of the project to date. However, it is intended that all samples will be subjected to both accelerated and outdoor exposure tests in Washington, D. C. It would be extremely desirable to expose specimens in an area where they would be subjected to wind-blown sand, but no such condition is encountered in this section of the country. However, if the Department of the Navy has facilities for exposure of specimens to such conditions, samples could be prepared in this laboratory and shipped to the selected installation and returned after exposure for evaluation.

4. RESULTS

4.1 Tentative Agenda

An outline of the work in the order in which it was to be performed was first drawn up. This tentative agenda is reproduced in Appendix 2.

4.2 Procurement of Samples

A standard form letter was mailed to twenty basic suppliers of plastic coatings and resins, in which requests for materials for use in this investigation were made, along with information regarding their properties and methods of application. The letter and a list of the companies to which it was sent constitute Appendices 3 and 4.

4.3 Review of Literature

A comprehensive study was made of the abstracted literature on abrasion resistance from 1907 to 1950. The most important publications pertaining to this subject are listed in Appendix 5. A brief statement of their scope, presented categorically, follows:

4.3.1 Kuroda[1]* in discussing the mechanism of the abrasion of metals proposes the following system of classification:

I. Pure dynamic abrasion
  A. Abrasion between solids
    (1) Elastic abrasion
    (2) Scratching abrasion

The author theorized that abrasion between solids is the result of fatigue failure. He calculated the pressure at the contact surface between two abrading bodies followed Hertz's formula. This pressure becomes quite large and as it is added to every point on the surface successively, the material receives a severe repeated load. The result is that the sustained fatigue failure causes the abrasion.

The relationship between hardness and abrasion resistance of plastics is discussed by Boor, Ryan, Marks and Bartoe[2]. The authors define the "hardness" of plastics as resistance to indentation and observed that this hardness is not necessarily a measure of mar, scratch or wear resistance.

F. Campus, A. Dantinne, and A. Jacquemin [3] reported that a linear relationship exists between the quantity of abrasive used and the thickness of the specimen. They also observed that the base to which the coating is applied has an influence on the quantity of abrasive used. For example, the quantity of sand for the same wear is much greater for a steel base than for a wrought iron base, and yet/ greater for a wrought iron base than for a glass base. The authors also reported that if the quantity of abrasive (ordinate) is plotted as a function of film thickness (abscissa), the line (for the same base) intersects the abscissa axis at a value which can be considered as an expression of abrasion.

*Figures in parenthesis indicate literature references in Appendix 5.

In a paper published in 1934, Milligan[4] demonstrated a relationship between crystallographic orientation and abrasion hardness in the case of feldspar and quartz crystals by producing impact abrasion by an accurately controlled blast of "Standard Ottawa Quartz Sand" (20-30 mesh, round-grain, silica-quartz sand). In his experiments with abrading grains, other than quartz sand, he showed that corresponding hardness values for such hard materials as crystalline alumina and silicon carbide came much closer together when hard artificial abrasive grains are used for blasting.

4.3.2 Test Methods Utilizing Unsupported Abrasives

The results of work done by the Bell Telephone Laboratories were reported by A. E. Schuh and E. W. Kern[5] in March 1931. The measurement of abrasion resistance of paints, varnishes and lacquers was determined by the employment of the following test method: Carborundum powder of uniform particle size was admitted at a constant rate to a directed stream of air under constant pressure. The resulting blast was allowed to impinge upon a film of the test material at a fixed angle. The abrasion resistance was evaluated in terms of the weight of Carborundum required to wear through a unit thickness of the material. For the testing of paints, varnishes and lacquers, the authors observed that the following conditions of operation were well adapted:

1. Position of Test Specimen - Flush against the edge of nozzle at an angle of 45° inclination.
2. Air Pressure - 6 cm of mercury.
3. Rate of Flow of Carborundum - 34 g per minute.
4. Particle size - 170-200 mesh.

Spencer-Strong[6] described a method in which he employed a simple inexpensive apparatus for determining relative abrasion resistance of enamels. He obtained abrasion by fixing the specimen in the path of a stream of sand, propelled by a rapidly-revolving disc. He reports that the severity of the abrasive action is dependent upon the particle size of the abrasive.

In June 1939, the Scientific Section, National Paint, Varnish and Lacquer Association, Inc., issued a circular covering an improved abrasion apparatus. Sward[7] described improvements in the operation of the falling sand abrasion apparatus and outlines an indirect method of indicating abrasion resistance by means of gloss measurements.

Marks and Conrad[8] describe an abrasion tester utilizing an emery blast as the abrasive. The abrasive action was evaluated in terms of scattered light. The authors observed that the amount of light scattered was proportional to the abrading action on the specimen.

4.3.3 Results of Abrasion Tests

In a memorandum report issued in August 1944 by Materiel Command, Army Air Forces[9], it was reported that of 13 transparent plastics tested by a modified test procedure of A.S.T.M. D673-42T, only three indicated good mar resistance. They are (1) an allyl base plastic, (2) methyl methacrylate coated with an abrasive resistant material manufactured by du Pont and (3) plate glass. The remaining materials gave results which indicated poor to fair abrasion resistance. It was further reported that in field tests (one year outdoor exposure in Mojave Desert, Blythe Field, California), not one of a variety of plastic specimens exposed showed any but minor abrasion caused by sand. However, in actual service tests (windows installed on a C-40 airplane), polished plate glass was about four times as abrasion resistant as any plastic used.

Preliminary results reported by Robertson, Lobisser and Stein[10] show that rubber-coated glass cloth laminates give complete protection when they are used for air-borne radar-antenna housings flown at high speeds through rain.

After subjecting twenty-nine coatings, spun on glass, to various mar and abrasion tests, Doles, Schmidt, Levy and Wheatley[11] concluded that Allymer CR-39 (Columbia Chem. Div., Pittsburgh Plate Glass Co.) was most resistant to marring. An alkyd modified melamine (Strathmore Products) was second best, followed by Vibrin 1305 (Naugatuck Chem. Co.), diallyl phthalate (Shell Development Co.) and a combination of CR-39 (Ta) and diallyl phthalate.

Marks and Conrad[8], using an emery blast method, reported that CR-39 showed the best results of some 18 plastics tested.

4.4 Abrasion Apparatus

The abrasion comparator apparatus adopted is basically of the same construction as that described in Section 2.2. The specimen is mounted vertically on a stage at a distance of 10 inches from

[illegible] specimens.

[illegible]

[illegible]

[illegible] (10) [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

the sand blast nozzle. It is masked by a 1/16" brass plate having a one-inch aperture which sharply defines the abraded pattern on the specimen. The apparatus is equipped with a shutter-like arrangement by which the exposure time of the specimen to the blast can be accurately controlled. For the initial tests, the following set of conditions were selected:

Abradant - 60-200 mesh sand.
Rate of feed of abradant - 7 g/minute.
Air Pressure - 9 psi.
Distance of specimen from Nozzle - 10 inches.
Exposure Time - 0, 5, 10, and 20 seconds.
Size of Pattern - 1 inch diameter.

In order to give an indication of the results obtained with the abrasion apparatus in terms of haze, fifteen glass specimens were subjected to abrasion under the conditions stated above. The samples were then carefully washed in warm water, wiped dry, and the haze determined. The results of the series of tests are presented in Table 1.

TABLE 1.

GLASS

Exposure Time, Seconds	Td	Ts	% Haze*	% Deviation from Mean
0	91.1	0.1	.1	
[illegible]	90.7	8.1	9.1	
[illegible]	86.6	11.9	13.5	
4	85.[illegible]	19.6	22.6	
5	84.0	21.4	25.5	7.1
5	85.5	20.1	23.7	0.0
5	84.[illegible]	23.1	27.4	8.2
10	81.7	41.1	50.4	1.0
10	81.4	41.0	50.4	1.4
10	81.5	42.[illegible]	52.1	2.2
15	80.1	51.6	61.7	1.6
15	80.[illegible]	50.[illegible]	62.[illegible]	1.7
15	79.[illegible]	51.[illegible]	64.[illegible]	1.9
20	78.1	59.5	75.7	

*Values of haze are uncorrected for the original haze of the glass.

4.5 Transparent Coatings

A number of plastic materials available in the laboratory were used as a protection for glass and subjected to the abrasive action of the apparatus described above. Tables 2a and 2b present the results as obtained by visual observation.

TABLE 2a.

Material	Adhesive	Adhesion	Results Material	Glass
Scotch Tape	Pressure sensitive	Excellent	Etched	O.K.
Cellulose Acetate	Acryloid	Fair	"	O.K.
Nylon-Type 1	Solvent (alcohol)	Poor	"	O.K.
" Type 2	Solvent (alcohol)	Poor	"	O.K.
" Type 1	Acryloid	Fair	"	O.K.
" Type 2	Acryloid	Fair	"	O.K.
Pliofilm	Rubber cement	Good	Not etched	O.K.
Photographic Emulsion	None	Excellent	Etched	Etched

TABLE 2b.

Material	Method of Application	Adhesion	Results Material	Glass
Acryloid	By brush	Good	Etched	O.K.

5. CONCLUSIONS

The preliminary data obtained with the abrasion comparator apparatus indicates that it is a sound method to evaluate the abrasion resistance of coating materials. The photometric method for measurement of haze gave, in the initial tests, results which checked each other to within 6% (see Table 1). Results that check within 3% are considered good for this type of testing and it is felt this goal can be attained.

In regard to the protection afforded by plastic coatings, four of the five materials which were tried shielded the glass from attack, but all except one were badly marred in the process. In addition, a photographic emulsion failed to give any protection against air-driven sand under the conditions employed. The results of the tests on the plastic coatings were not surprising for all were relatively hard materials and marred quite easily. It is felt that a material that has the property of high elasticity (such as rubber) would be resistant to the etching effect, due to its complete recovery after indentation, whereas, glass or similar material would etch very easily, due to its inherent brittleness.

C. FUTURE WORK

The order in which future studies are contemplated appears below:

Task 1 - Calibration of the abrasion apparatus.

Task 2 - The investigation of the methods of application of the solution-type coatings to glass.

Task 3 - To investigate the possibility of utilizing preformed, transparent sheet materials for the protection of glass. This task may include a literature survey on adhesion, with emphasis on pressure sensitive adhesives.

Upon completion of the three tasks and with the development of a satisfactory system for determining the relative abrasion resistance of coating materials, future work will be confined largely to evaluating materials that are available.

Because of the limited nature of this investigation, materials that will be evaluated are restricted to finished products except in a few cases where manufacturers have submitted ingredients for compounding coatings.

In regard to the [illegible] of the five materials [illegible]

[illegible]

4. [illegible]

The manner in which [illegible] below:

Task 1 – [illegible]

Task 2 – The investigation of [illegible]

Task 3 – To investigate the [illegible]

Upon completion of the three tasks [illegible]

[illegible]

APPENDIX 1.

PROJECT TITLE

Protective Coatings for Glass and Metals in Desert Areas

BACKGROUND

(1) The abrasive action of wind-blown sand in desert areas is sufficient to render opaque glass windows and windshields in relatively short periods and to damage metal surfaces. The field of organic plastic coatings would seem to be a logical area for investigation in this connection. Some work has been done on the resistance of plastic coatings to weathering and the effect of abrasion on the transparency of such coatings.

(2) Intensive sunlight in desert areas make difficult the handling of metal tools and other metal objects. This problem will involve the reflective coatings that will provide adequate thermal insulation. We have no present knowledge of work done that would apply directly to this problem.

OBJECT

The objects of work under this project are:

(1) To investigate the suitability of various types of coatings for protecting glass and metal surfaces from the abrading effects of wind-blown sand and, if possible, prepare tentative recommendations for coating materials for field tests.

(2) To evaluate the non-conductive and reflective properties of coatings for metal tools and other metal objects and, if possible, prepare tentative recommendations for coating materials whose use will permit handling with bare hands metal objects exposed to the sun for long periods in desert areas.

OUTLINE OF WORK TO BE DONE

Part 1. Protection from wind-blown sand.

Obvious requirements of a satisfactory material are that it must adhere well to the surface to which it is applied and that it will resist normal weathering and abrasion. Preliminary work will consist of a search of the literature and the obtaining of all information possible from other sources.

Task 1. Literature search and search for information from other sources.

APPENDIX I continued

Task 2. Evaluation of selected materials by existing test procedures.

Task 1 could be started immediately and could be completed in two months.

Task 2 would be started on the completion of Task 1 and would probably be completed by December 31, 1952.

Part 2. Evaluation of protective coatings for metals and tools.

Coatings of the type desired will have to adhere well, resist shocks due to handling and resist normal weathering. The first work would consist of a literature search and preliminary tests of various types of coatings to determine the physical reactions involved with their use.

Task 1. Literature search and search for information from other sources.

Task 2. Evaluate selected coatings with regard to thermal conductivity and emissivity.

Task 1 could be started immediately and would be completed in about two months.

Task 2 would be started on the completion of task 1 and would be completed by December 31, 1952.

APPENDIX C.

Tentative Agenda

1. Report covering literature survey.
   a. Abrasion resistance.
   b. Test methods utilizing unsupported abrasives.
   c. Preliminary survey of adhesion (pressure sensitivity).

2. Standard form letter for sample requests.

3. Test Methods.
   a. For impingement of sand.
   b. For measurement of haze.
   c. For evaluation of wearability, strippability, ease of application, weathering, temp. rise or "feel".

4. Methods of Application.
   a. Spray or brush.
   b. Doctor blade.
   c. Flow and drain or spin dry.

5. Experimental Conditions.
   a. Film thickness (0.0005 to 0.05").
      Maximum of 3 thicknesses per sample.
      Pre-formed sheets where possible.
   b. Size and number of specimens.
      1. Haze meter (4) 2" x 5" glass plates.
      2. Weathering (4) 2-3/4 x 6" glass plates.
      3. Metal plates (2).
   c. Materials to be tested.
      1. Plastics, butyl acrylate and other high acrylate
      2. Rubber latex solutions
      3. " " emulsions
      4. Saran "
      5. Organic silicones
      6. Na siliconate
      7. Glycerol, oils, greases
      8. Glycerol soaps
      9. Waxes
      10. Surface hardened varnishes
      11. Fatty-acid-pitch base coating
      12. Inorganics, e.g., silicic acid, Na silicate, phosphates. Sols.

APPENDIX C *continued*

Factors to be considered

1. "On location" application desired.
2. Specifications for new vehicles not primary aim.
3. Permanency of coating not necessary.
4. Hardness of coating not a criterion.
5. Transparency of coating desired, not necessary.
6. Tool coating problem can be attacked simultaneously.
7. Photographic record may be desirable. Material may be dyed with crystal violet.
8. Test method should use sand. Fine, air-blown sand is preferred.
9. Work can be organized into 3 problems:
    a. Wear resistance necessary for permanent application of difficultly applied material.
    b. Cost of material and its application is the major item for strippable coatings.
    c. Ease of re-plating is important for replenishable coatings.

APPENDIX 1.

Standard Form Letter

Subject: Abrasion Resistant Coatings
(Project [illegible])

Gentlemen:

We have undertaken, at the request of one of the Defense Agencies, a study of transparent coatings that will resist abrasion from wind-driven sand. The coatings are intended primarily for use on glass and metal. Weather resistance and adhesiveness are necessary characteristics except for coatings that are readily strippable.

We would like to purchase two one-quart samples of the coating of your manufacture that you consider most promising for our purpose. If the material is also available in sheet form, we would like to have approximately three square feet in this form.

With the sample we would like to have as complete information as possible regarding the following:

Composition
Recommended methods of application
Recommended time of application
Spreading rate
Time and special conditions for drying
For sheet materials, techniques for bending
Information regarding abrasion tests performed
Cost
Availability
Any published descriptive literature

In projects of this kind, complete data are reported to the agency sponsoring the work. Any data that might be published later would omit reference to manufacturer's or brand names. Opportunity to discuss the work with your technical representatives is welcomed and we are glad to show such representatives the results of tests on their product. Reference to Bureau work for advertising or sales promotion purposes is not permitted.

APPENDIX I CONTINUED

Since this is an urgent matter, it is requested that you forward sample and data promptly. A Government Bill of Lading to cover transportation is attached. Material should be shipped to the attention of the undersigned, reference Project No. 4700, National Bureau of Standards, Washington 25, D. C. Make invoices to National Bureau of Standards, Project 4700.

Your cooperation is greatly appreciated.

Very truly yours,

H. R. Snoke, Chief
Floor, Roof and Wall
Coverings Section.

APPENDIX 4.

List of Companies to which Standard Form Letter was Sent.

1. Reichhold Chemicals, Inc.
2. American Cyanamid Company
3. Bakelite Company
4. Plaskon Division, Libbey-Owens-Ford Glass Co.
5. G-E Chemical Dept., General Electric Co.
6. Plastics Dept., E. I. duPont de Nemours, Inc.
7. Shell Chemical Corporation
8. Rohm and Haas Company
9. Goodyear Tire and Rubber Company, Inc.
10. Plastics Division, Monsanto Chemical Co.
11. Better Finishes and Coatings, Inc.
12. B. F. Goodrich Company
13. Pittsburg Plate Glass Company
14. Minnesota Mining and Manufacturing Co.
15. Dow Chemical Company
16. Stanley Chemical Company
17. Lilly Varnish Company
18. Stoner-Mudge Company
19. Mobile Paint Manufacturing Company
20. Naugatuck Chemical Division, U. S. Rubber Co.

APPENDIX 5.

References

(1) "On the Mechanism of the Abrasion of Metals", Masao Kuroda, Trans. Soc. Mech. Engs. Japan, 5, 5-99, 1939.

(2) "Hardness and Abrasion Resistance", T. Boor, J. D. Ryan, M. E. Marks and W. F. Bartoe, A.S.T.M. Bull., 68-73, 1947.

(3) "Testing of Paints and Lacquers", F. Campus, R. Dantinne, and R. Jacquemin, Rev. Universelle Mines, 15, 427-39, 1939.

(4) "Impact-Abrasion Hardness of Certain Minerals and Ceramic Products", T. H. Milligan, Jour. Amer. Ceram. Soc., 19 (7), 187-91, 1936.

(5) "Measurement of Abrasion Resistance. Paints, Varnishes and Lacquers", A. E. Schuh and E. W. Kern, Ind. Eng. Chem., Anal. Ed. 3, 72-6, 1931.

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(8) "Resistance of Plastics to Abrasive Particles", M. E. Marks and Paul Conrad, Modern Plastics, 23, 165, March 1946.

(9) "Abrasion Tests for Transparent Plastics", Memorandum Report, Eng. Div., Materiel Command, Army Air Forces, 18 August 1944.

(10) "High Speed Rain Abrasion of Glass Cloth Laminates", R. McG. Robertson, R. J. Lobisser, and R. E. Stein, Ind. Eng. Chem., 38, 590-1, 1946.

(11) "Optical Lens Coatings", H. W. Coles, W. F. Schulz, S. Levy, and T. A. Wheatley, Modern Plastics, 25, 123, July 1946.